

Consolidated Edison BESS Program

In Reference To:

Report No. OAPUS301WIKO(PP151894), Rev. 4
February 9th, 2017

Summary of Main Findings

This document summarizes the main findings and recommendations from extensive fire and extinguisher testing on a broad range of battery chemistries. The testing was conducted through much of 2016 on behalf of the New York State Energy Research & Development Authority (NYSERDA) and Consolidated Edison, as they engaged the New York City Fire Department (FDNY) and the New York City Department of Buildings (NY DOB) to address code and training updates required to accommodate deployment of energy storage in New York City.

This document is a supplement to the main report and should not be considered a replacement. Details about the testing program can be found in the report issued by Consolidated Edison and NYSERDA. Supporting data or evidence to any claim listed in this summary can be found in the report with detailed cross references. The conclusions and findings are sorted into general subject areas for organizational purposes. The original report was finalized on January 18th, 2017.¹

Toxicity

- All battery chemistries tested exhibited toxic emissions under fire scenarios.
- The average emissions rate of a battery during a fire condition is lower per kilogram of material than a plastics fire. However, the peak emissions rate (during thermal runaway of a Li-ion battery, for example) is higher than a plastics fire.
- The vanadium redox and lead acid batteries tested both emitted HCl upon heating, starting as low level emission around 100-150°C.

Codes Updates

- Large systems and small systems should have an intelligent means of addressing ventilation and fire suppression with a scalable metric that correlates to size or mass, rather than an arbitrary kW, kg, or kWh number as what is proposed in upcoming IFC, IEC, and NFPA codes.
- Energy and power densities for systems are perpetually evolving and improving. Arbitrarily prescribing a kW, kWh, or kg number to limit system installation threatens the value proposition of energy storage in the coming future.
- In proposed changes to IFC 608, 20 kWh is cited as a threshold for battery sizes or 600 kWh in a room. The code also proposes 3ft of clearance between battery arrays. Such prescription threatens the value proposition of energy storage as energy and power density metrics have been increasing rapidly over the last 5-8 years.
- The IEC 62619 propagation test outlines pass/fail criteria to demonstrate limited failure to a single module. DNV GL recommends that cell failure be limited to the smallest unit of assembly, i.e. a single cell, which exceeds most standards requirements but also limits the ultimate fire load, which directly reduces the cooling requirement from water extinguishing. Present test accreditations may be adequate as long as appropriate considerations for external fire rating and cooling (via water suppression) are incorporated into the requirements for fire suppression.
- DNV GL recommends that when calculating the air flow and water extinguishing rate, one must account for battery energy density (only the battery cells, not the entire system) as well as the duration of the event.

¹ A clarification on the present day requirements for IEC 62619 was added on February 9th, 2017.

First Responders

- It is recommended that whenever possible, first responders need not open or otherwise disperse burned battery modules and wait for an experienced liaison to arrive on site and take ownership of the site after extinguishing has been achieved.
- If water submersion is used by first responders for isolating spent modules, preparation to deal with alkaline or basic water for disposal should be a consideration.
- After extinguishing, continued ventilation and monitoring of the area with gas monitors is highly recommended.
- DNV GL and the provider of turnout gear (Honeywell Morning Pride) did not note degradation in PPE as a result of exposure to a battery fire when the gear was fit on a mannequin and exposed to the fire directly.
- Batteries may have residual voltage on damaged and exposed terminals. Handling of the battery may produce a shock hazard.
- Batteries persistently gassed even under water. The primary measured component of that gas was CO, though the handheld CO sensors are cross sensitive to H₂.
- For most tests the water runoff was slightly acidic measuring pH 6-7. In one case, however, the water became alkaline climbing to pH 10-11 after a few hours of submersion. This case was observed for a battery that was highly consumed in the fire.
- Batteries did not climb in temperature after submersion under water, indicating that even if cells short circuited, their temperature was never permitted to climb to thermal runaway conditions.
- Some battery cells still had voltage on them after 24 hours of submersion. While some cells may have shorted, not all shorted. The water did not have any additives such as salt to make it more conductive.
- Under the conditions tested, equipment available to present day first responders can be considered adequate for battery fire fighting under the conditions tested

Project Development

- With these considerations, DNV GL recommends that system portfolios undergo a risk analysis, with particular attention paid to:
 - Cascading protections between cells and modules
 - Clearances to structures above the energy storage systems
 - Fire rating of the enclosure
 - Most probable expected failure mode
 - If a battery is demonstrated to have a non-flammable electrolyte, there may be considerations for a reduced water extinguisher requirement, or at a minimum a water requirement equivalent to that required for the space without battery systems installed.
- It is highly recommended that battery systems installed within buildings have an established emergency contact list and a subject matter expert (SME) who can arrive on the scene to take over containment, cleanup, and eventual disposal of damaged battery equipment. This recommendation requires involvement from the project development and systems integration community.
- Some engagement between the systems integration, project development, and first responder community is needed to discuss viable solutions for a state of health panel, or whether the intent of the panel is met through other means (such as an emergency hotline or remote data access by phone or other means).

Systems Integration and Battery Design

- DNV GL recommends a minimum 1 hour fire rating with a 2 hour rating in areas with critical population density, and that the fire rating be considered as part of a system level approach to avoid cascading fires.

- DNV GL recommends that all systems demonstrate that a single cell failure cannot propagate to neighbor cells in a module design. Present standards limiting fire from a module may be adequate, provided external fire ratings and adequate extinguishing metrics are met.
- If appropriate precautions are not taken to limit propagation between cells in the module design, then the water extinguishing flow rate may require a resultant increase.
- The combined effect of external fire rating and internal cascading protections works to limit the heat transfer rate, thereby reducing the overall water requirement.
- DNV GL recommends at a minimum that an error status panel, emergency response contact, or other form of error notification be available to first responders, and that the energy storage supply chain engage with first responders to propose a viable solution.

Ventilation

- Because the volume of the room plays a key role in dictating the ventilation rate, batteries in larger rooms will have lower air change per hour (ACH) requirements and the size of the room will have a buffering effect on the peak emission rate.
- The ventilation requirements should be the same for all battery chemistries tested in this program because they all have varying degrees of HCl or similar toxic emission upon heating.
- HCl plays a dominating role in ventilation rates for battery systems in enclosed spaces, and because it is common for all battery types tested, ventilation recommendations are universal for all battery types.
- However, it should be noted that in the smallest unit of failure scenarios, the recommended ventilation rate of 0.25 ACH is well below the typical rating of 3-4 for most general spaces which means that Vanadium Redox and Pb Acid batteries, as well as single cell failure modes for Li-ion, are already within the implied code requirements. Laboratories and server rooms can have ACH ratings > 10. Therefore the DNV GL recommendation for air change rates > 0.25 ACH is already exceeded by the building code in most instances.
- The ventilation requirement is sized to the IDLH of HCl, the flammability concern is also mitigated. The suggested ventilation rates range from 0.2-0.03 CFM/kg or 0.2-0.32 CFM/kWh. This translates to roughly 0.25 ACH in many cell failure scenarios, climbing to as high as 10-14 ACH in the worst case. , it is HCl, not HF, that governs the ventilation and toxicity consideration.

Extinguishing

- As testing progressed, DNV GL was able to reduce the water requirement from 1.7 GPM/kg at the module level to 0.1 GPM/kg. Conservative factors accounting for water contact efficiency have resulted in DNV GL's recommendations for 0.1 GPM/kg as an extinguishing benchmark.
- DNV GL recommends a minimum flowrate of 0.07-0.1 GPM/kg of batteries to accomplish both extinguishing and cooling for a battery fire. Accommodation for increasing energy density can be accomplished by dividing this number by the energy density (in Wh/kg) and multiplying by 1000 Wh/kWh. Rating systems at 0.1 GPM/kg provides a conservative factor for water contact efficiency with the cells.
- Water is the most effective cooling extinguisher. DNV GL's testing indicates that all extinguishers have benefits and drawbacks, including water. Every extinguisher that DNV GL tested put out the flame on battery cells, including the aerosol. During module testing, all extinguishers tested extinguished the flame but in some cases the flame rekindled once the stream was removed because the battery was still hot enough to ignite the remaining fuel. The ideal battery fire extinguisher would be both highly thermally conductive and highly electrically insulating. Water is the former but not the latter, yet its accessibility and cooling effectiveness make it preferable to most first responders.
- If the module has adequate cascading protections and a 1 hour fire rating, there is an opportunity to contain the cell failure and avoid the issue of oversizing the water requirement to the peak and instead size the water requirement to the battery mass.

- If the water can be targeted at the deep seated, highest temperature areas of the fire, it will be most effective and the water requirement will be reduced.
- It should be noted that the water contact efficiency averages 1-2%. This highly conservative number greatly drives the water requirement estimation. Any method by which a battery manufacturer or system integrator can demonstrate that the water contact efficiency is higher will reduce the water requirement overall.
- Upon extinguishing, great care must be taken to assure that all electrical, thermal, and mechanical abuse factors are neutralized. If the heat deep within the module has not been removed, that heat poses a continued thermal hazard.
- A Li-ion cell can smolder for more than an hour if the heat transfer rate is slow. By the time temperatures of 120°C (248°F) were reached, all Li-ion batteries tested (including LiFePO₄ and LTO chemistries) offgassed and/or ruptured. If the threshold near 120°C is never crossed, the battery may smolder and gas but never ignite unless an external spark ignites the flammable gases emitting from it.
- Because of the rapid evolution of a cell fire, DNV GL does not see an advantage to using a Class D extinguisher on a single cell or system fire.
- Because cooling is an inevitable need, a fixed suppression gas agent may reduce or mitigate flammability in an environment until ventilation and/or cooling strategies are implemented.
- DNV GL recommends staged extinguishing:
 - Stage 1: If a system has adequate protections against cell cascading (as would be indicated by a more stringent requirement than current versions of UL 1973 internal fire test or IEC 62619 internal propagation test), a gas based suppression system may be considered for the first stage of fire fighting to extinguish a single cell fire and prevent flashover in a contained environment.
 - Stage 2: If temperatures continue to rise or if an increasing level of smoke and gas is detected, forced ventilation and water extinguishing should be considered to cool the system and prevent further propagation of fire.
- During extinguishing, Rescue Methods did not observe transfer of electricity from the battery system to the first responder through the water stream.

Heat Release Rate and Failure Modes

- The ability to vent and relieve pressure is critical to whether the cell's failure is benign or sudden. This illuminates the fact that trapped gases are the cause of explosive failure.
- The emissions rate varies for all batteries but the upper and lower boundaries of emissions limits. The emissions rates corresponded to 0-57% mass loss over a period of 13-83 minutes.
- The HRR was observed to be anywhere from 2-8 kW with 100-800 g of released materials. This brackets the value from 2.5 – 80 kW/kg. By comparison, burned specimens of common furniture items have demonstrated a mass weighted HRR of 32-260 kW/kg.
- The flammable gases generated from the battery are the main source of explosion risk. These gases need to be vented to reduce the risk. Based on the nonlinear behavior of emitted gases a variable speed fan should be a consideration.
- There is a very direct increasing relationship between mass lost and the SOC before failure. The BMS limits the SOC of the battery intentionally for both longevity and safety reasons. The decline in mass loss is significant as the SOC of the battery is decreased from 100% to 90% or 80%.